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GERIOMETRY: A CUMULATIVE STRESS/DAMAGE MEASUREMENT OF USEFUL LI--ETC(U)
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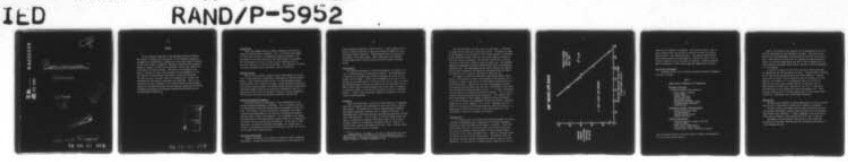

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(6) GERIOMETRY: A CUMULATIVE STRESS/DAMAGE MEASUREMENT OF USEFUL LIFE OF MECHANICAL SYSTEMS

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PREFACE

It has long been understood in the equipment design and development shops of industry, that the useful life of mechanical systems is consumed by an accumulation of damage due to the broad range of stresses to which the system is subjected. Heretofore, measuring the cumulative damage as a means of assessing the remaining life has been impractical, particularly for mobile systems. The advent of microcomputers now makes it possible to keep a running measure of this damage and to use this measure to help optimize the system's continuing reliability. The name *Geriometry* has been coined to distinguish this process--the measurement of the system's continuing life expectancy. Used in conjunction with trend assessment of the system condition and performance capability, Geriometry provides the most powerful capability yet applied to manage (and minimize) maintenance resources while maximizing continuing system reliability.

Introduction

Ground and highway vehicles, whether operated by the military, commercial enterprises or consumers, live in a difficult environment for which they are often ill prepared and poorly maintained. The environment is difficult because of the broad range of use patterns and the propensity of users to ignore routine maintenance and to drive the vehicle until failure has occurred. This practice, of course, increases maintenance costs and reduces vehicle reliability.

Improved Designs

There are two principal avenues by which improvements can be made. First is the reduction of maintenance requirements by improved vehicle design. Some available options include, (1) low maintenance designs using synthetic oils, bearings and seals; sealed bearings and batteries; and coolant recovery systems, (2) modular designs employing standardized, replaceable modules which can be recycled or disposed of, and (3) co-operative designs including diagnostic connectors, onboard diagnostics, telltale wear indicators and improved maintenance accessibility.

Advanced Maintenance Management

The second avenue for improvement is the implementation of advanced maintenance management techniques. This, in essence, requires an understanding of when the optimum time for maintenance action is at hand. The concept is called "on-condition" maintenance and requires a quantitative measurement of the fraction of subsystem performance available and/or useful life remaining. This information would enable the performance of maintenance before system reliability is jeopardized and without excessive maintenance intervention. In the case of fleet operations, on-condition maintenance management will improve the allocation of maintenance and operational resources, and thus the utility of the fleet, while reducing costs.

Performance Measurement

Numerous techniques are available for measuring vehicle subsystem performance. Perhaps the most promising approach is the extension of

onboard computers employed in engine control.* These systems will be sensing and processing much of the same information needed for calculating performance capability. Added capability may be required for data memory, and output display. Major subsystems to be assessed include engine power, cooling system, electrical system, and brake system.

Trend Analysis

For certain performance or condition parameters, the useful lifetime is characterized by a smooth decay function. The examination of a time series of snapshot tests (point estimates) can reveal the progression of this decay. Criteria for maintenance of the vehicle subsystems can be established as a function of the level to which the decay has progressed and/or the rate of change (slope) of the decay function. Other criteria have also been proposed such as the level or frequency of vibration spikes, or the ratio of the third to the first vibration harmonic. Useful criteria obviously depend on the nature of the subsystem failure signatures.

Geriometry

There are limitations to the use of trend analysis for subsystems where the performance trend characteristic does not follow a predictable pattern. An extreme case is that of the performance parameter that remains essentially constant until a sudden failure point. A thermostatically controlled cooling system might be expected to exhibit such a characteristic. In such cases, it has been common practice to employ an inspection of physical conditions and/or to use a time or mileage criteria for triggering a maintenance action. Physical inspection often requires disassembly which may, itself, introduce added unreliability and is costly to perform.

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*General Motors' President, E. M. Estes, stated before the recent annual Automotive Service Industry Association convention, the expectation that all GM gasoline-powered cars will be equipped with an onboard computer as standard equipment by 1981.

The term Geriometry has been coined by the author to describe a concept for measuring the system aging process. Geriometry is based on the hypothesis that the physical life of many systems is determined by the cumulative damage resulting from a broad range of stresses to which the system is subjected. The stresses include time, activity, inactivity, transients, vibration, physical abuse, etc. The weighted, cumulative measurement of these stresses forms a basis for estimating remaining life. This measurement can be used to enhance and supplant certain other performance and condition assessments where the latter are expensive or less precise indicators of remaining life.

An example is drawn from some work at the General Motors Corporation. An assessment of brake life was made for two hundred cars in the hands of owners, revealing a life distribution ranging from 20 to 120 thousand miles. Seven of the cars were instrumented to measure the average energy dissipated per mile and a correlation of this parameter with wearout mileage was made (see Fig. 1). A linear relationship results which has an interesting and useful property. It is a line of constant cumulative braking energy dissipation. This suggests that a direct measurement of this property (cumulative energy dissipated) is an index to brake life, independent of the user patterns, from which remaining life can be computed. It is also of importance that this useful life property can be determined during controlled testing, i.e., development or qualification tests, rather than requiring this determination in actual or simulated user patterns.

Implementation

It is proposed that on-condition maintenance management for ground vehicles be implemented with a combination of condition assessment, performance trend assessment and Geriometric accounting. These techniques would reveal all significant safety and reliability hazards; the choice of parameters would be made to minimize inspection/monitoring costs for a given confidence level. Condition assessment would be largely by visual and audio observation. Performance trends and Geriometric accounts would be maintained by onboard computing instrumentation. For new vehicles, an added marginal capability for the on-

GM* BRAKE LIFE DATA

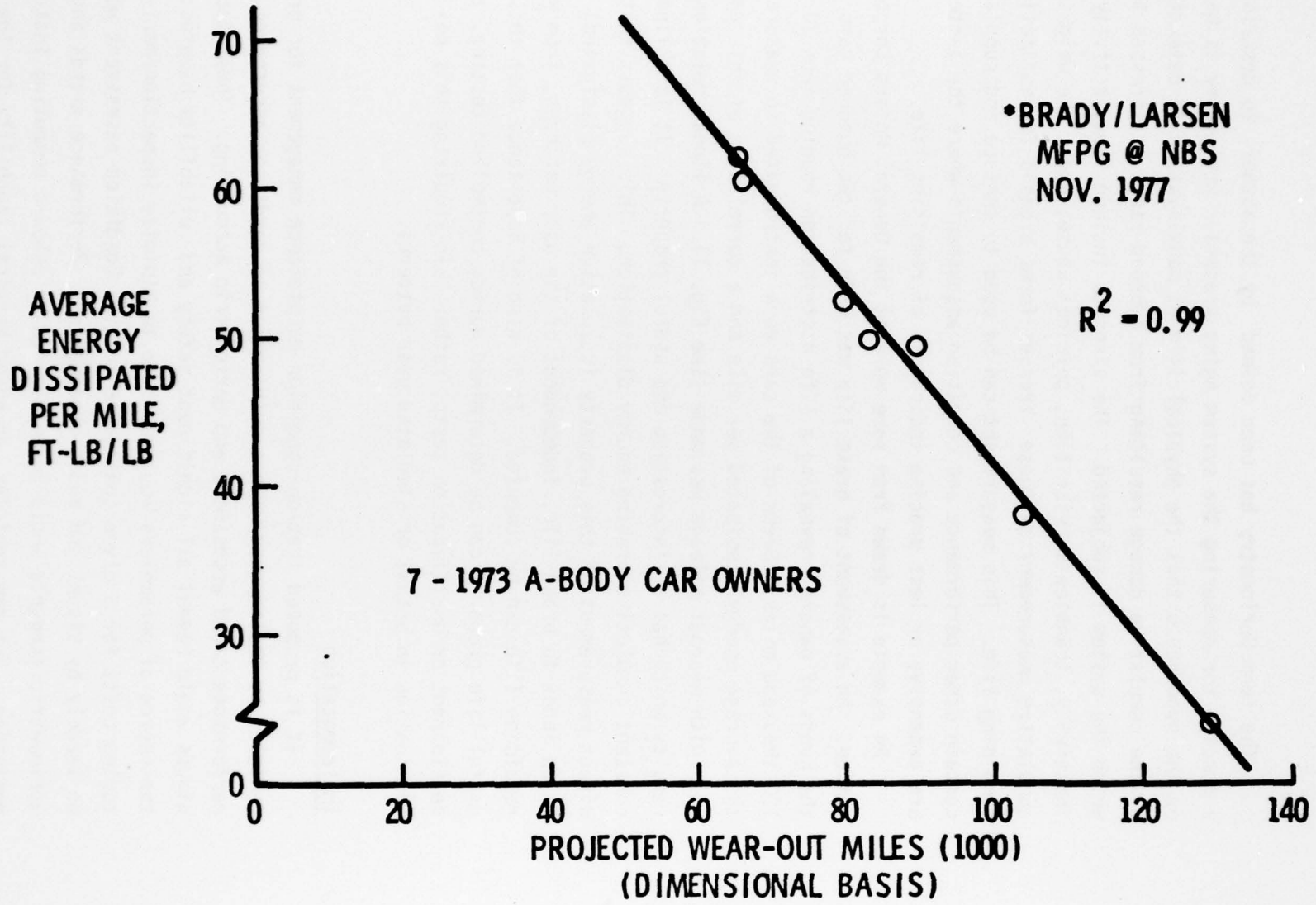

FIGURE 1

board control computer is suggested. For existing vehicles, the on-board computer should be designed to minimize the need for vehicle-mounted sensors and connecting harness. One possible mechanization would employ vibration accelerometers in conjunction with a clock, a battery connection, and a hard physical mounting. Signature analysis would be employed to infer engine speed and temperature transients.

Application Development

A proposed initial set of vehicle on-condition analysis parameters would be as follows:

Table 1

GROUND VEHICLE REMAINING LIFE FORMULATION

Geriometric Accounts

(Cumulative-Stress Time-Integrals)

- Engine Speed Transients
- Piston Speed
- Thermal Transients
- Cold Loading Time
- Deceleration Energy
- Acceleration/Vibration Energy
- Current/Voltage Transients
- Cranking Time

Performance Snapshot Trend Assessment

- Engine Acceleration Power
- Cylinder Balance
- Charge/Starting Current
- Exhaust Emissions

Condition Observables

- Physical Condition--Damage, Corrosion
- Tires/Alignment
- Power Train, Exhaust Noise
- Belt Tension, Hose Condition
- Liquid Levels, Color, Time since Exchange

Only the exhaust emission test would require offboard instrumentation in the current state-of-the-art.

Useful life data will be necessary to the development of the calculation algorithms for the Geriometric accounts. Much data can be derived from the development and qualification tests for existing systems. Some additional testing will be required to develop weighting factors for various damage mechanisms and to explore appropriate signature analyses techniques where indirect sensing of vehicle parameters is to be employed.

It would be assumed initially that relatively simple algorithms are appropriate for the Geriometric accounts. Stresses which contribute to the same failure mechanisms would be assumed additive. Stresses which cause different failure mechanisms would be assumed to be independent. For example, if it is determined that piston speeds of 3000 ft/minute will cause cylinder wearout at 1000 hours and of 2000 ft/minute at 5000 hours, 500 hours of the first in combination with 2500 hours of the second would constitute wearout life. Other stresses contributing to cylinder wearout would include engine speed transients, loading when cold, and thermal transients.

Applications

Geriometry has potential for broad application, not only to ground vehicles but to other mobile systems and to industrial equipment.

Military logistic and combat vehicle fleets can benefit not only from improved maintenance resources allocation but also from improved quantifiable fleet readiness. A combat commander can plan more effectively with confidence in the availability of his unit's vehicles.

Geriometry also has potential application in the inspection/assurance of the safety, emission and fuel consumption performance of in-use highway vehicles.